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# High Resolutional Real Time Acoustic Microscopy

## **Abstract**

A commercially available scanning-laser-acoustic-microscope (SLAM) has been developed which provides new and unique analytical capabilities for materials science and non-destructive testing. By employing 100 MHz acoustic waves to create images, the "elastic microstructure" of complex materials is visualized directly. The "acoustic micrographs" which contain  $2 \times 10^4$  image points, are displayed on a real time TV monitor. The sample remains accessible to the investigator during the procedure and stressing fixtures can be employed. Dynamic activities can be recorded either on movie film or video tape. There are two acoustic imaging modes which appear to be essential for flaw and defect characterization. The first mode displays the acoustic transmission level through the sample (normal mode) and the second mode displays fringes related to the acoustic phase (interference mode). The presence of a defect within a sample may be evidenced by a change in transmission level or a change in phase or both. The nature of the defect (e.g. high density inclusion or void) can be determined through the combined analysis of the interference and normal mode micrographs. The SLAM technique has been applied to a wide variety of materials including ceramics, metals, glasses, polymers, etc. Defect localization down to 25  $\mu\text{m}$  has been achieved. Samples can be systematically searched, area by area, by simply repositioning the part on the stage of the microscope and observing the acoustic image on the TV monitor.

## **Keywords**

Nondestructive Evaluation

## **Disciplines**

Materials Science and Engineering

## HIGH RESOLUTION REAL TIME ACOUSTIC MICROSCOPY

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### ABSTRACT

A commercially available scanning-laser-acoustic-microscope (SLAM) has been developed which provides new and unique analytical capabilities for materials science and non-destructive testing. By employing 100 MHz acoustic waves to create images, the "elastic microstructure" of complex materials is visualized directly. The "acoustic micrographs" which contain  $2 \times 10^4$  image points, are displayed on a real time TV monitor. The sample remains accessible to the investigator during the procedure and stressing fixtures can be employed. Dynamic activities can be recorded either on movie film or video tape. There are two acoustic imaging modes which appear to be essential for flaw and defect characterization. The first mode displays the acoustic transmission level through the sample (normal mode) and the second mode displays fringes related to the acoustic phase (interference mode). The presence of a defect within a sample may be evidenced by a change in transmission level or a change in phase or both. The nature of the defect (e.g. high density inclusion or void) can be determined through the combined analysis of the interference and normal mode micrographs. The SLAM technique has been applied to a wide variety of materials including ceramics, metals, glasses, polymers, etc. Defect localization down to  $25 \mu\text{m}$  has been achieved. Samples can be systematically searched, area by area, by simply repositioning the part on the stage of the microscope and observing the acoustic image on the TV monitor.

### Introduction

Modern analytical instrumentation has played an important role in materials analysis and non-destructive testing. Microscopy, for example, has broadened our knowledge of fine structure and our understanding of structural components. Ultrasonic equipment has enabled flaw detection at the millimeter size level. The most recent addition to the arsenal of analytical instrumentation is the acoustic microscope. This instrument produces an entirely new and unique view of fine structure. While the optical and electron microscope techniques differentiate the visual, molecular and ultrafine features of a specimen, acoustic microscopy can differentiate structure on the basis of physical properties which are not accessible by the other techniques. In materials science, "mechanical" properties are of prime importance in the service behavior of metals, ceramics, etc., influencing such important phenomena as crack initiation and propagation. The acoustic microscope provides access to the internal "microelastic" structure rather than the "visible" aspects at a surface crosssection. Furthermore, structures can be differentiated within thick, optically opaque samples since acoustic wave propagation does not suffer the same restrictions as electromagnetic wave propagation.

### The Basic Technique

The SONOMICROSCOPE 100 is a commercially available scanning laser acoustic microscope (SLAM) which produces optical and acoustic micrographs simultaneously. The frequency of ultrasound is 100 MHz and has also been extended to 500 MHz for certain applications in very thin materials. The configuration for viewing specimens

is analogous to that used in optical microscopy, in that the sample is placed on a stage where it is both insonified and illuminated. The invisible pattern of sound transmitted through the specimen is detected by means of a rapidly scanning laser-beam-microphone. This pattern, which is the acoustic micrograph, is displayed on a TV monitor. An optical image of the sample is also derived from the laser scan and this is displayed on the adjacent TV monitor. The micrographs are produced in real time, thereby permitting dynamic activity (such as fracture phenomena) to be studied. A block diagram and photograph of this instrument are shown in Figs. 1 and 2, respectively.

With reference to Fig. 2, the 100 MHz acoustic signal is produced by a piezoelectric material bonded onto an applicator stage. The specimen placed upon the microscope stage is coupled via a fluid film at the interface. The energy transmitted through the sample modulates the focused laser beam as it rapidly scans the field of interest. The reflected laser beam is received at a photodetector whose output consists of two signals; one signal depends upon visual features of the surface and the other signal is proportional to the acoustic amplitude. The signals are filtered separately amplified, and converted to video signals for display on the TV monitors. Thus optical and acoustic images appear simultaneously. This technique achieves high resolution, high sensitivity, and real time TV images.

If the specimen is not optically reflective a mirrored coverslip may be placed on top of it and acoustically coupled by means of a drop of fluid. The acoustic signal causes minute displacements to the coverslip surface, thereby modulating the laser beam.



There are two types of acoustic amplitude pictures. First are amplitude pictures made at a single ultrasonic frequency. These acoustic micrographs are generally characterized by high contrast and could also be subject to coherent speckle. The amount of speckle is related to the degree of scattering in the specimens, and this provides some indication of both the mode of acoustic losses, as well as the elastic microstructure of the material under investigation. The second type of amplitude picture is obtained by continuously sweeping the frequency over a selected range. This eliminates coherent speckle and may reveal low contrast features which could have been masked.

In addition to displaying the acoustic amplitude distribution throughout the field of view, the SLAM provides an acoustic interference mode of operation. Acoustic interferograms show a series of alternating light and dark stripes. For acoustically homogeneous samples, these bands, or interference fringes, are parallel to one another and are equally spaced. For samples that have variations in acoustic index of refraction or variations in thickness the interference lines will be shifted accordingly. Quantitative velocity of sound measurements may be obtained from the interferograms using simple formulas. Because most of the samples investigated have controlled thicknesses the character of the interferograms is determined solely by localized variations in the velocity of sound. These variations arise from either density or compressibility, or both.

The choice of the visualization modes is made by electronic switching, thus no repositioning of the sample is required.

#### Advantages of Acoustic Microscopy

Acoustic micrographs provide a new and unique perspective of structure, i.e. that which relates to the microelastic features. Some of the advantages that should be considered are listed below:

1) Optical opacity in thick samples of metal, ceramic, etc. can be avoided with acoustic microscopy; internal structures are differentiated on the basis of intrinsic elasticity variations among the structural components.

2) Microstructure within solids can be observed nondestructively without resorting to laborious sectioning, polishing and etching.

3) The real time feature of the technique permits investigation of dynamic behavior, for example, materials under stress can be observed during the formation of plastic zones and during fracture initiation.

4) Physical elastic properties of structure are brought out by acoustic microscopy. Quantitative data on acoustic index of refraction are available with acoustic interference microscopy. The acoustic interferograms are related to the compressibility and density characteristics of the sample on a micro size scale.

5) Simultaneous acoustic and optical micrographs are produced by the scanning laser technique, thus newly revealed acoustic features can be directly correlated with an optical reference image. Two TV monitors operate simultaneously to provide these views and, thus, the sample need not be disturbed in any way.

6) Acoustic microscopy also plays an important role in biomedical research. Soft and hard tissues can be differentiated, details of muscular contraction can be observed, etc. without exposure to ionizing radiation. Interesting studies performed on hard tissues, such as bone and tooth, revealed variations in microelastic properties which seem to play an important role in the overall functional behavior of the body.

Table 1. Example Application Areas

Welding Flaws	Films
Porosity	Epoxy Bonding
Polymerization Defects	Elasticity and Density
Plastics and Polymers	Variations
Paper	Dynamic Behavior
Non-destructive Testing	Diffusion Bonding Defects
Microstructural Integrity	Delaminations
Metals and Alloys	Defect & Flaw Localization
Internal Fractures	Debonding
Inclusions	Composite Materials
Heat Treatment Effects	Coatings
Glasses	Ceramics
Geological Samples	Anisotropy
Fracture Mechanics	Adhesive Bonds

#### Acknowledgement

This study is described by R. J. Bratton, C. A. Anderson, and F. F. Lange EPRI Report on Ceramics Rotor Blade Development, May 15, 1976, under contract RP 421-1, p. 3-14 to 3-19.



Figure 1. Scanning Laser Acoustic Microscope (SLAM): A commercially available SLAM is shown in the top photo. Two television monitors display the optical and acoustic micrographs simultaneously. A close-up of the stage of isonifying the sample is shown in the bottom photo. The micrometers are used to orient and position the stage and the sample remains accessible to the operator at all times. The operating frequency of this instrument is 100 MHz nominal and specialized stage modules may be dropped in for varying the angle of isonification and the energy mode, i.e., compressional or shear waves.

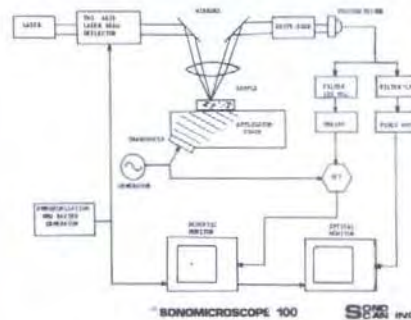


Figure 2. Principle of Operation of the Scanning Laser Acoustic Microscope: A 100 MHz acoustic signal is applied to a specimen placed upon the microscope stage. Acoustic energy transmitted through the sample modulates the non-contacting laser beam as it rapidly scans the field of interest. The reflected laser light is detected by a photodiode whose output consists of two signals; one depends upon visual features of the surface and the other is proportional to the acoustic amplitude. The signals are amplified and displayed on separate TV monitors as optical and acoustic micrographs, respectively. This technique achieves high resolution, high sensitivity, and real time visual displays. If the sample surface does not reflect the laser light then a mirrored coverslip is placed on top of it. The acoustic energy is coupled to the coverslip by means of a drop of fluid.



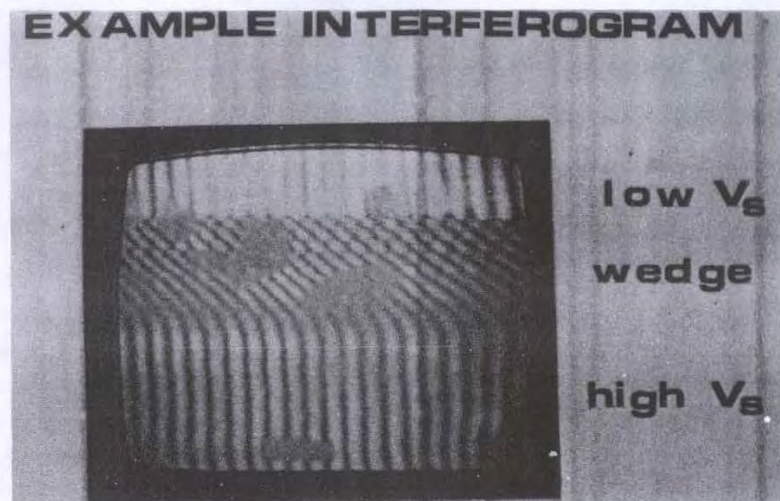


Figure 3. Example Interferogram: An acoustic interferogram displays spatial variations of acoustic transit time in a sample. In order to produce this information, the acoustic transmission signal is combined with a reference signal and, like holography, the resulting fringe spacing corresponds to the spatial angle separation between the object and reference beams. This figure is an interferogram of a 2-phase sample composed of low velocity of sound on the bottom. The sample is uniformly thick and the transition between the materials is shaped as a wedge. Interference fringe shifts to the right indicate less transmission time or higher velocity of sound. The fringe spacing is 80 microns. In an arbitrary specimen, the fringe positions may be readily analyzed to yield velocity of sound data everywhere throughout the field of view.

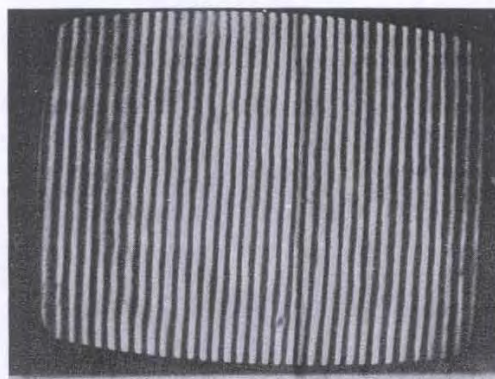


Figure 4. Clean Hot Pressed  $\text{Si}_3\text{N}_4$ : Uniform attenuation and velocity of sound over a field of view is characteristic of "good" hot pressed  $\text{Si}_3\text{N}_4$ . This figure shows an example of such a material. The interference fringes are uniformly straight and evenly spaced.



Figure 5. WC Inclusion Within Hot Pressed  $\text{Si}_3\text{N}_4$ : A 2-inch diameter disc, 1/8-inch thick, of hot pressed  $\text{Si}_3\text{N}_4$  was fabricated with inclusions of known sizes and locations as shown. The actual disc is shown in (a). An acoustic micrograph of a large tungsten carbide inclusion is shown in (b), and the corresponding interferogram fringes are spaced apart by 80 microns. Many of the small dark structures surrounding the large defect are seen to contain phase variations, thus indicating elastic inhomogeneity. Tungsten carbide and boron nitride inclusions were observed on the SLAM down to 50 microns in size. In addition, unintentional heterogeneous elastic variations in the  $\text{Si}_3\text{N}_4$  were detected at the 50  $\mu$  level.